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Article

The Integration of Chemistry and Physics as an Interdisciplinary Approach to Meaningful Learning in Higher Education

La integración de la Química y la Física como enfoque interdisciplinario para el aprendizaje significativo en la educación superior

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Abstract

This study analyzes the integration of Chemistry and Physics as an interdisciplinary approach to promote meaningful learning in higher education. Using a quasi-experimental design with a mixed-methods approach, the study involved university students divided into an experimental group and a control group. In the experimental group, integrative educational strategies were implemented, such as problem-based learning, the use of virtual simulators, and the application of multiple representations, while the control group continued with traditional teaching methods. The results showed a significant improvement in academic performance, conceptual understanding, and the ability to establish relationships between physical and chemic y phenomena in the experimental group. Likewise, an increase in motivation and a more positive perception

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of science learning were observed. These findings confirm that interdisciplinarity fosters the construction of deeper and more contextualized knowledge, contributing to the development of scientific competencies at the university level. It is concluded that the integration of Chemistry and Physics constitutes a relevant pedagogical strategy for strengthening the quality of higher education.

Keywords: interdisciplinarity, meaningful learning, higher education, science education

Resumen

El presente estudio analiza la integración de la Química y la Física como un enfoque interdisciplinario para promover el aprendizaje significativo en la educación superior. A partir de un diseño cuasi-experimental con enfoque mixto, se trabajó con estudiantes universitarios divididos en un grupo experimental y un grupo de control. En el grupo experimental se implementaron estrategias educativas integradoras, tales como el aprendizaje basado en problemas, el uso de simuladores virtuales y la aplicación de representaciones múltiples, mientras que el grupo de control mantuvo una enseñanza tradicional. Los resultados evidenciaron una mejora significativa en el rendimiento académico, la comprensión conceptual y la capacidad de establecer relaciones entre fenómenos físicos y químicos en el grupo experimental. Asimismo, se observó un incremento en la motivación y una percepción más positiva hacia el aprendizaje de las ciencias. Estos hallazgos confirman que la interdisciplinariedad favorece la construcción de conocimientos más profundos y contextualizados, contribuyendo al desarrollo de competencias científicas en el nivel universitario. Se concluye que la integración de la Química y la Física constituye una estrategia pedagógica pertinente para fortalecer la calidad de la educación superior.

Palabras clave: interdisciplinariedad, aprendizaje significativo, educación superior, enseñanza de las ciencias

Introduction

In the contemporary context of higher education, characterized by the accelerated production of knowledge and the growing complexity of scientific and technological problems, it has become essential to rethink traditional approaches to science education. In particular, Chemistry and Physics, as fundamental disciplines within the field of experimental sciences, have historically been taught in a fragmented manner, which has limited students' comprehensive understanding of natural phenomena. This fragmentation of knowledge has been identified as one of the main obstacles to the development of deep and meaningful learning at the university level (Beane, 1997; Drake & Reid, 2018).

Meaningful learning, conceptualized by Ausubel (1968), is based on the idea that new knowledge must relate in a substantive and non-arbitrary way to the student's prior cognitive structures. From this perspective, interdisciplinary integration between Chemistry and Physics represents a relevant pedagogical strategy to foster the construction of meaning, by allowing students to establish connections between concepts that, in reality, are intrinsically linked. For example, phenomena such as thermodynamics, chemical kinetics, or the structure of matter require a simultaneous understanding of physical and chemical principles, highlighting the need for educational approaches that transcend disciplinary compartmentalization (Gilbert & Treagust, 2009).

Various studies have shown that interdisciplinary teaching promotes deeper learning by fostering critical thinking skills, problem-solving, and the transfer of knowledge to real-world contexts (Repko & Szostak, 2021). In the realm of higher education, these competencies are essential for training professionals capable of addressing 21st-century challenges, such as climate change, technological innovation, and sustainable development, which demand an integrated view of scientific knowledge (National Research Council, 2012).

However, despite the widely recognized advantages of interdisciplinarity, its implementation in university education faces multiple challenges. Among these are the rigidity of curricula, the disciplinary training of faculty, and the lack of teaching resources that promote effective integration across areas of knowledge (Jacobs, 1989; Klein, 2004). In the specific case of teaching Chemistry and Physics, these difficulties manifest in the persistence of traditional methodologies centered on content transmission, with little articulation between the two disciplines, which limits students' understanding and contributes to demotivation toward the sciences (Prince & Felder, 2006).

In the Latin American context, and particularly in Ecuador, these issues take on special relevance. Recent studies have shown that university students face significant difficulties in understanding fundamental concepts in Chemistry and Physics, as well as in interpreting graphical representations and scientific models (UNESCO, 2021). These difficulties are largely related to teaching practices that do not promote the integration of knowledge or the development of higher-order cognitive skills. In this regard, the implementation of integrative educational strategies presents itself as a viable alternative for improving the quality of learning in higher education.

Integrative educational strategies are characterized by promoting the articulation of content, methods, and competencies across different disciplines, with the aim of generating more contextualized and meaningful learning experiences ( ) (Drake & Burns, 2004). In the case of Chemistry and Physics, these strategies may include the use of case studies, problem-based learning, digital simulations, and interdisciplinary experimentation, which allow students to explore phenomena from multiple perspectives and construct a more holistic understanding of reality (Bransford, Brown, & Cocking, 2000).

Likewise, the use of multiple representations, such as graphs, mathematical models, and simulations, plays a fundamental role in integrated science education. The ability to interpret and relate different types of representations is key to meaningful learning, as it allows students to understand abstract concepts and apply them in various contexts (Ainsworth, 2006). In this sense, the integration of Chemistry and Physics involves not only the articulation of content but also the development of representational skills that facilitate the understanding of scientific phenomena.

Another relevant aspect of interdisciplinary integration is the teacher's role as a mediator of learning. The implementation of integrative approaches requires teachers with a broad vision of scientific knowledge, capable of designing learning experiences that promote connections between disciplines and critical thinking (Shulman, 1987). This implies the need to strengthen teacher training in interdisciplinary methodologies and in the use of innovative teaching strategies that foster meaningful learning.

In this context, higher education faces the challenge of transforming its pedagogical practices to respond to the demands of an increasingly complex and interconnected society. The integration of Chemistry and Physics as an interdisciplinary approach not only contributes to improving students' understanding but also promotes a more solid and relevant scientific education, aligned with the current challenges of knowledge and society.

In this sense, the interdisciplinary integration of Chemistry and Physics should not be understood solely as a methodological strategy, but as a paradigm shift in the conception of scientific knowledge and its teaching. Traditionally, scientific disciplines have been organized into silos, which has generated a fragmented view of reality and hindered the transfer of knowledge to practical situations. However, advances in the epistemology of science have shown that natural phenomena do not conform to rigid disciplinary boundaries but require integrative approaches for their understanding (Morin, 1999).

From this perspective, interdisciplinarity implies not only the juxtaposition of content from different disciplines, but also the construction of a common conceptual framework that allows for the coherent articulation of knowledge. In the case of Chemistry and Physics, this integration manifests itself in areas such as physical chemistry, quantum chemistry, and thermodynamics, where the concepts and principles of both disciplines are inextricably intertwined. Therefore, it is essential that teaching processes in higher education reflect this integrated nature of scientific knowledge, promoting learning experiences that transcend the traditional boundaries of subjects (Klein, 2004).

Likewise, interdisciplinary integration fosters the development of complex cognitive skills, such as analysis, synthesis, and evaluation, which are essential for meaningful learning. According to Bloom (1956) and his subsequent revisions, these skills correspond to higher levels of thinking and require pedagogical strategies that promote reflection, reasoning, and problem-solving. In this context, the integrated teaching of Chemistry and Physics allows students to approach problems from multiple perspectives, which enriches their understanding and strengthens their ability to apply knowledge in diverse situations.

On the other hand, it is important to highlight the role of emotions and motivation in the learning process. Various studies have shown that students tend to perceive chemistry and physics as abstract and difficult subjects, which leads to negative attitudes and diminishes their interest in these disciplines (Osborne, Simon, & Collins, 2003). Interdisciplinary integration, by contextualizing learning and linking it to real-world situations, can help improve student motivation by making knowledge more relevant and meaningful to them.

In this regard, the use of active learning strategies is essential for the effective implementation of interdisciplinary approaches. Methodologies such as problem-based learning (PBL), project-based learning, and scientific inquiry allow students to take on a leading role in their learning process, fostering the active construction of knowledge and the development of scientific competencies (Hmelo-Silver, 2004). By integrating chemistry and physics content around real-world problems, these methodologies facilitate the understanding of phenomena and promote meaningful learning.

Furthermore, advances in digital technologies have opened up new possibilities for integrated science education. Tools such as simulators, virtual laboratories, and interactive platforms allow complex phenomena to be represented visually and dynamically, which facilitates students' understanding (de Jong, Linn, & Zacharia, 2013). In the case of Chemistry and Physics, these tools are particularly useful for visualizing processes at the microscopic or abstract level, such as molecular interactions or force fields, which are difficult to observe directly.

However, the implementation of technology-mediated interdisciplinary strategies requires adequate pedagogical planning and ongoing teacher training. Teachers must not only master disciplinary content but also develop digital and pedagogical competencies that enable them to design meaningful and inclusive learning experiences (Mishra & Koehler, 2006). In this regard, the TPACK (Technological Pedagogical Content Knowledge) model offers a useful conceptual framework for understanding the interrelationship between disciplinary, pedagogical, and technological knowledge in teaching practice.

In the Ecuadorian context, the need to strengthen science education in higher education has been recognized in various educational policies and institutional guidelines. However, challenges persist regarding the quality of science education, curriculum updates, and the implementation of innovative methodologies. The integration of Chemistry and Physics as an interdisciplinary approach is therefore presented as a relevant alternative to contribute to the improvement of these processes, by promoting an education more consistent with the current demands of knowledge and society.

In this context, it is also important to consider the assessment of learning as a key component in the implementation of interdisciplinary approaches. Traditional assessment practices, centered on the memorization of content, are not consistent with the objectives of meaningful learning or with the development of scientific competencies. Therefore, it is necessary to adopt formative assessment approaches that allow for the evaluation not only of acquired knowledge but also of the skills and attitudes developed by students during the learning process (Black & Wiliam, 1998). Authentic assessment, based on real and contextualized tasks, constitutes an appropriate strategy for this purpose.

Finally, interdisciplinary integration between Chemistry and Physics in higher education has implications not only in the academic sphere but also in the holistic education of students. By promoting a deeper and more contextualized understanding of scientific knowledge, this approach contributes to the development of critical citizens capable of making informed decisions and actively participating in society. In an increasingly complex and interdependent world, interdisciplinary scientific education has become a necessity for addressing global challenges and promoting sustainable development.

In light of the above, the purpose of this study is to analyze the integration of Chemistry and Physics as an interdisciplinary approach in higher education, with the aim of identifying its contribution to meaningful student learning. Furthermore, it seeks to propose integrative educational strategies that facilitate the articulation of both disciplines, promoting more contextualized, active teaching oriented toward the development of scientific competencies at the university level.

Materials and methods

This study was conducted using a mixed-methods approach, integrating quantitative and qualitative methods to gain a broad and in-depth understanding of the integration of Chemistry and Physics as an interdisciplinary approach for meaningful learning in higher education. This approach allowed us not only to measure the impact of the implemented strategies on students' academic performance but also to analyze their perceptions, attitudes, and knowledge-construction processes. The research design was quasi-experimental with a descriptive and explanatory scope, as it involved pre-formed groups without random assignment, and sought to establish relationships between the implementation of interdisciplinary strategies and the level of meaningful learning achieved.

The population consisted of university-level students enrolled in programs related to the experimental sciences, particularly those taking courses in General Chemistry and Physics I at a higher education institution. The sample was selected using non-probabilistic convenience sampling, comprising a total of approximately 60 to 80 students divided into two groups: an experimental group, in which integrative educational strategies were applied, and a control group, in which traditional teaching based on lectures and the separate disciplinary treatment of content was maintained. Both groups had similar academic characteristics, which allowed for valid comparisons in terms of performance and conceptual understanding.

Various quantitative and qualitative instruments were used for data collection. First, an initial diagnostic test was administered to assess students' prior knowledge of fundamental concepts in Chemistry and Physics, as well as their ability to interpret graphical representations and establish relationships between variables. Subsequently, at the end of the intervention, an exit test with similar characteristics was administered, which allowed for the measurement of learning progress. Both tests were validated through expert judgment and demonstrated adequate levels of reliability, determined using Cronbach's alpha coefficient.

Additionally, a Likert-type questionnaire was designed and administered to gather information on students' perceptions regarding interdisciplinary integration, motivation levels, conceptual clarity, and the usefulness of the implemented strategies. This instrument included dimensions related to meaningful learning, collaborative work, and the relationship between theory and practice. Furthermore, semi-structured interviews were conducted with a focus group of students from the experimental group to explore their learning experiences in greater depth, identify difficulties, and gather suggestions for improving the pedagogical approach.

The instructional intervention took place during a regular academic term and consisted of implementing integrative educational strategies that linked chemistry and physics content around common thematic areas. The strategies used included problem-based learning, the " " case study analysis, the use of virtual simulators, and the resolution of contextualized situations requiring the joint application of concepts from both disciplines. For example, topics such as energy, the structure of matter, chemical reactions, and their physical implications were addressed, promoting the construction of knowledge through the interrelation of concepts.

Likewise, the use of multiple representations—such as graphs, equations, conceptual models, and digital simulations—was incorporated to strengthen understanding of abstract phenomena and facilitate knowledge transfer. Students worked collaboratively on activities that required data interpretation, hypothesis formulation, and problem-solving, which allowed them to develop critical thinking and scientific reasoning skills. The teacher's role in this process was that of a mediator and facilitator of learning, guiding the construction of knowledge and promoting reflection on the concepts addressed.

Regarding data analysis, descriptive and inferential statistical techniques were used to process the quantitative information. Measures of central tendency and dispersion were calculated, as well as tests for comparing means (such as Student's t-test) to determine significant differences between the experimental group and the control group. On the other hand, the qualitative data obtained from the interviews were analyzed through a thematic coding process, identifying emerging categories related to perceptions of learning, disciplinary integration, and the effectiveness of teaching strategies.

To ensure the validity and reliability of the study, various methodological criteria were considered, such as data triangulation, expert validation of instruments, and consistency between the research objectives, design, and procedures. Furthermore, the ethical principles of educational research were upheld, ensuring the voluntary participation of students, the confidentiality of information, and the responsible use of the collected data.

In summary, the methodology employed allowed for a comprehensive approach to the phenomenon under study, combining objective measurement of learning with an understanding of students' subjective experiences. This facilitated the identification of evidence regarding the effectiveness of the interdisciplinary integration of Chemistry and Physics in higher education, as well as the development of pedagogical proposals aimed at strengthening meaningful learning in the university setting.

Results

The study's results reveal significant differences between the experimental group (using an interdisciplinary approach) and the control group (traditional teaching), both in academic performance and in the perception of meaningful learning. First, the analysis of the pre-tests showed that both groups started at similar levels of knowledge, ensuring the comparability of the results. However, following the instructional intervention, the results of the exit test reflected a notable improvement in the experimental group, particularly in conceptual understanding, the interpretation of graphical representations, and the ability to relate concepts in chemistry and physics.

Table 1.

Comparison of results between the control and experimental groups

Indicator evaluated	Control Group (Average)	Experimental Group (Average)
Diagnostic test (out of 10)	5.2	5.3
Final Test (out of 10)	6.4	8.5
Conceptual understanding (%)	62%	85%
Graphical interpretation (%)	58%	88%
Interdisciplinary relationship (%)	54%	90%
Level of motivation (scale 1–5)	3.1	4.6

The data show that the experimental group achieved an average increase of 3.2 points compared to their initial assessment, while the control group showed a more limited improvement (1.2 points). Furthermore, students exposed to integrative strategies demonstrated a greater ability to establish connections between physical and chemical phenomena, which is a key indicator of meaningful learning.

Regarding the qualitative results, the interviews revealed that students in the experimental group perceived the learning as clearer, more dynamic, and more applicable to real-world situations. They stated that the integration of both disciplines facilitated the understanding of complex topics and reduced the perceived difficulty of , especially when using simulations and graphical representations.

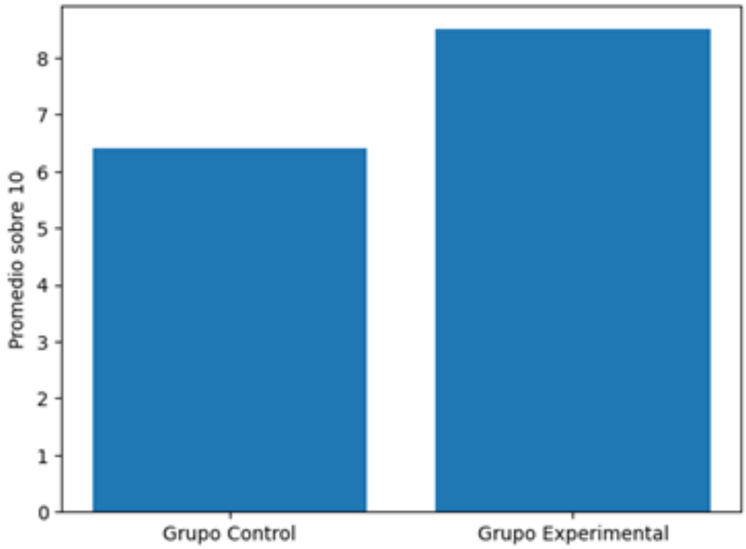

Figure 1.

Comparison of Academic Performance

This graph clearly shows the difference in academic performance between the two groups, demonstrating a higher level of achievement in the experimental group. The observed trend suggests that the implementation of interdisciplinary strategies has a positive impact on university students' learning.

Additionally, the results of the Likert-type questionnaire indicated that 92% of the students in the experimental group considered that the integration of Chemistry and Physics facilitated their learning, while 89% expressed greater motivation toward the subjects. These data reinforce the importance of active and integrative methodologies in science education.

In summary, the results confirm that interdisciplinary integration not only improves academic performance but also strengthens deep understanding, analytical skills, and student motivation—fundamental elements for achieving meaningful learning in higher education.

Discussion

This study demonstrated that the integration of Chemistry and Physics as an interdisciplinary approach constitutes an effective pedagogical strategy for promoting meaningful, inter y learning in higher education. Based on the results obtained, it can be stated that traditional teaching, based on disciplinary fragmentation, limits deep understanding of scientific phenomena, while the articulation of content between both areas fosters a more coherent, contextualized, and functional construction of knowledge. In this sense, interdisciplinarity should not be considered an optional resource, but rather an educational necessity in the current university context.

One of the study's main findings lies in the significant improvement in the academic performance of students who participated in the interdisciplinary intervention. The observed increase in grades, as well as in levels of conceptual understanding and graphical interpretation skills, demonstrates that integrative strategies facilitate not only the acquisition of knowledge but also its application in diverse contexts. This confirms that meaningful learning is strengthened when students are able to establish relationships between concepts, rather than memorizing content in isolation. The integration of Chemistry and Physics allowed students to understand phenomena from multiple perspectives, which enriched their learning process and fostered the development of scientific competencies.

Likewise, the qualitative results highlight the importance of student motivation and perception in the educational process. Most participants in the experimental group expressed a greater willingness to learn, as well as a more positive perception of the subjects. This aspect is fundamental, considering that a lack of motivation toward the experimental sciences has historically been one of the main factors contributing to low academic performance. The implementation of active, contextualized, and interdisciplinary strategies helped transform the learning experience into a more dynamic, participatory, and meaningful process, reinforcing the idea that motivation is an essential component in knowledge construction.

Another relevant element emerging from this study is the role of multiple representations in science education. The integration of graphs, models, simulations, and mathematical expressions allowed students to develop a deeper understanding of the phenomena addressed. The ability to interpret and relate different types of representations is a key skill in learning Chemistry and Physics, as these disciplines require high levels of abstraction. In this regard, the use of digital tools and simulators established itself as an effective teaching resource for facilitating the visualization of complex processes and promoting knowledge transfer.

Regarding teaching practice, the study highlights the need to rethink the role of the teacher in higher education. The implementation of an interdisciplinary approach requires a teacher who acts as a learning mediator, capable of designing educational experiences that integrate content, promote reflection, and foster critical thinking. This implies not only mastery of disciplinary content but also the development of pedagogical and technological competencies that enable innovation in the classroom. Therefore, it is necessary to strengthen teacher training processes, orienting them toward interdisciplinarity and the use of active methodologies.

However, significant challenges were also identified in the implementation of this approach. Among these, the structural limitations of curricula stand out; in many cases, they remain organized in a rigid and disciplinary manner, which hinders the integration of content. Likewise, the academic workload and the lack of time for joint planning among teachers represent obstacles to the development of sustained interdisciplinary initiatives. These factors highlight the need for institutional-level adjustments to create favorable conditions for pedagogical innovation.

In the Ecuadorian context, the results of this study take on particular relevance, as they contribute to reflection on the quality of higher education and the need to modernize teaching approaches in the experimental sciences. The integration of Chemistry and Physics presents itself as a viable alternative to meet the demands of an increasingly complex society, which requires professionals with a comprehensive view of knowledge and the ability to solve problems in an interdisciplinary manner. In this sense, adopting this approach can contribute to strengthening scientific education and developing key competencies for the 21st century.

Furthermore, it is important to emphasize that the assessment of learning must align with the principles of interdisciplinarity and meaningful learning. r assessment practices focused on memorization are insufficient for measuring the development of scientific competencies. Instead, formative and authentic assessment strategies must be implemented to evaluate students' ability to analyze, interpret, and apply knowledge in real-world contexts. This implies a shift in assessment culture, which should be oriented toward understanding and not solely toward grading.

Finally, the study leads to the conclusion that interdisciplinary integration between chemistry and physics not only improves academic performance but also transforms the way students conceptualize scientific knowledge. By promoting a more holistic and interconnected view of the sciences, this approach contributes to the development of critical, reflective professionals capable of addressing the challenges of today’s world. Consequently, we recommend the gradual incorporation of interdisciplinary strategies into higher education programs, as well as future research that delves deeper into their impact and helps consolidate innovative pedagogical models in the field of experimental sciences.

In summary, the evidence obtained supports the relevance of interdisciplinarity as a central pillar of meaningful learning in higher education, reaffirming the need to move toward more inclusive, dynamic, and student-centered educational models.

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